Inclusive Open Charm Production in pp and Pb–Pb collisions with the ALICE Detector

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Abstract. ALICE is the dedicated heavy-ion experiment at the LHC. Its main physics goal is to study the properties of strongly-interacting matter at conditions of high energy density (>10 GeV/fm^3) and high temperature (> 0.5 GeV) expected to be reached in central PbPb collisions. Charm and beauty quarks are powerful tools to investigate this high density and strongly interacting state of matter since they are produced in initial hard scatterings that are therefore generated early in the system evolution and probe its hottest, densest stage. The measurement of the charm production cross sections in pp collisions provides an interesting insight into QCD processes and is crucial as a reference for heavy ion studies. We present open charm cross section measurements in pp collisions at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$=2.76 TeV in the central rapidity region. In addition, the first measurement of nuclear modification factor of D-meson in Pb–Pb collisions at $\sqrt{s}$= 2.76 TeV is shown.

1. Introduction

Heavy quarks are unique probes to study the Quark-Gluon Plasma produced in heavy ion collisions at the LHC. Due to their large masses, they are produced predominantly in hard scatterings, during the initial phase of the collision. Therefore, they can probe the properties of the strongly interacting matter during its hottest, densest phase. One of the key methods used to infer the parameters of the medium is the measurement of energy loss of the partons traversing it. In a QCD picture, radiative in-medium energy loss is one of the main mechanisms expected to contribute, with dependence on the mass and the colour charge of the particle. The radiation is suppressed at small angles for massive partons because of the dead-cone effect [1] and is larger for gluons, which have stronger color charge with respect to quarks (Casimir effect). Therefore one should observe a pattern of decreasing energy loss when going from the light flavour hadrons ($h^{\pm}$ or π^0) which mainly originate in gluon jets to D and B-mesons. The measurement and comparison of these different probes of the medium provides a unique test of the colour charge and mass dependence of parton energy loss [2].

Heavy-quark production measurements in pp collisions at the LHC, besides providing a necessary reference for the study of medium effects in Pb–Pb collisions, are interesting per se, as a test of perturbative QCD (pQCD) in a new energy domain, up to 3.5 times above the present energy frontier at the Tevatron. The charm production cross section measured in p$\bar{\text{p}}$ collisions at $\sqrt{s}$=1.96 TeV at the Tevatron [3] is at the upper limit of the uncertainty band in current pQCD caculations, as observed also in pp collisions at RHIC at the much lower energy of $\sqrt{s}$= 0.2 TeV [4].

2. ALICE Detector

The ALICE detector [5] consists of two parts: a central barrel at mid-rapidity and a muon spectrometer at forward rapidity. For the present analysis, we have used the information from a subset of the central barrel detector, namely the Inner Tracking System (ITS), the Time Projection Chamber (TPC), the Time Of Flight detector (TOF), the T0 detector for time zero measurement and the VZERO scintillator arrays for triggering. The two tracking detectors, the ITS and the TPC, enable the reconstruction of charged particle tracks in the pseudorapidity range $-0.9 < \eta < 0.9$ with a momentum resolution better than 4% for $\mathrm{p_t} < 20$ GeV/c and provide charged particle identification via a dE/dx measurements. The ITS is a crucial detector for open heavy flavour studies because it allows the track impact parameter (i.e. the distance of closest approach of the track to the primary vertex) to be measured with a resolution better than 75 μm for $p_t > 1$ GeV/c, thus providing the capability to detect the secondary vertices originating from heavy-flavour decays. The TOF detector provides particle identification by time of flight measurement.

The results that we present are obtained from data recorded with a minimum bias trigger in pp and Pb–Pb collisions. The trigger was defined by the presence of a signal at least one of two scintillator arrays, positioned in the forward and backward regions of the experiment, or in the silicon pixel barrel detector. For pp collisions, the D-meson production cross sections are normalized relative to the minimum-bias trigger cross section, which was measured using a van-der-Meer scan technique [6]. Pb–Pb collision-centrality classes are defined using a Glauber-model analysis of the sum of amplitudes in the VZERO scintillator detector. The total number of events analyzed is 100×10^6 (30% of 2010 data) for pp at 7 TeV, 67×10^6 (full data) for pp at 2.76 TeV and 17×10^6 for Pb–Pb at 2.76 TeV.

3. D meson Analysis in pp collisions

The detection strategy for D mesons at central rapidity is based on the selection of displaced-vertex topologies, i.e. discrimination of tracks from the secondary vertex from those originating in the primary vertex, large decay length (normalized to its estimated uncertainty), and good alignment between the reconstructed D meson momentum and flight-line. The identification of the charged kaon and pion in the TPC and TOF detectors helps to further reduce the background at low $\mathrm{p_t}$. An invariant-mass analysis is then used to extract the raw signal yield, which is then corrected for detector acceptance and reconstruction efficiency, which are evaluated using a detailed detector simulation. A significant fraction of D mesons (10-15%) comes from B-meson decays, and since the tracks coming from secondary D mesons are more displaced from the primary vertex, due to the relatively long lifetime of B mesons ($c\tau \sim$ 460-490 μm), the selection further enhances their contribution to the raw yield. To estimate this contribution, we used the FONLL [7] cross section for prompt and secondary D mesons at $\sqrt{\mathrm{s}} = 7$ TeV, since the available statistics were not sufficient to use data driven methods, as carried out by the CDF [3] collaboration. This contribution is subtracted from the measured raw $\mathrm{p_t}$ spectrum, before applying the efficiency correction.

Fig. 1 shows the preliminary $\mathrm{p_t}$ differential cross section for $\mathrm{D^0}$, $\mathrm{D^+}$, $\mathrm{D^{*+}}$ mesons in pp collisions at $\sqrt{\mathrm{s}} = 7$ TeV, compared to two theoretical predictions, FONLL [7] and GM-VFNS [8]. The measurements are well-described by both models within their theoretical uncertainties.

The same analysis was repeated for the pp data sample collected at $\sqrt{\mathrm{s}} = 2.76$ TeV, which is the same centre of mass energy as that of the Pb–Pb. The extrapolation of the D meson cross section measurements to the full kinematic phase space was used to estimate the total charm production cross section. This extrapolation was done using FONLL calculations, accounting for their uncertainty. The total inclusive charm production cross section as a function of center of mass energy, shown in Fig. 2, illustrates the compatibility of the different experiments [9, 10, 11, 12, 13], and the reasonable description of its energy evolution by the MNR pQCD

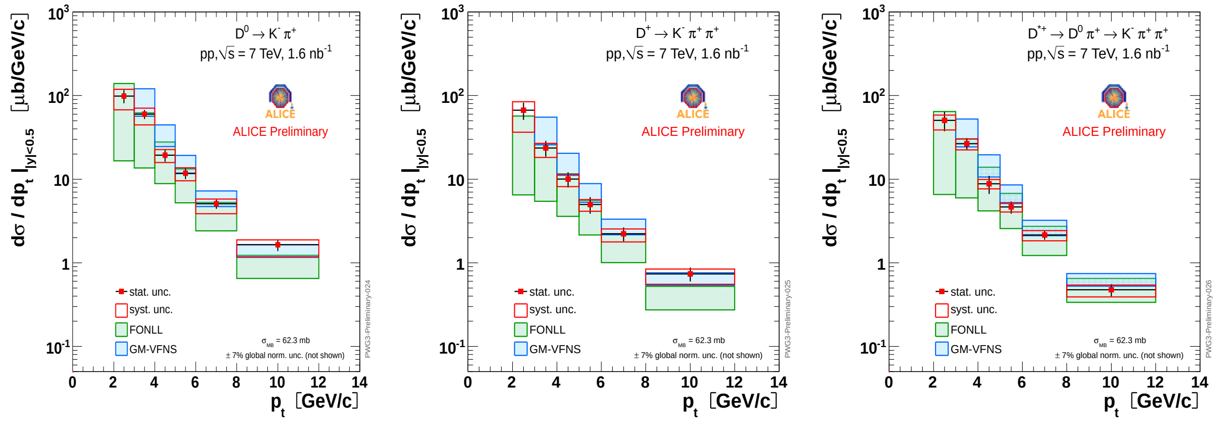

Figure 1. Preliminary p_t differential cross section for D^0 (left panel) and D^+ (middle panel), D^{*+} (right panel) in pp collsions at $\sqrt{s}$=7 TeV, compared to FONLL [7] and GM-VFNS [8] theoretical predictions.

calculations [14].

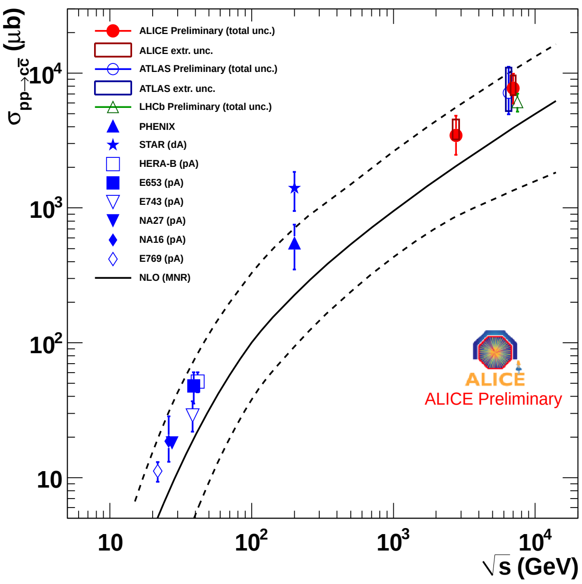

Figure 2. Total charm production cross section as a function of centre of mass energy for various experiments [9, 10, 11, 12, 13].

4. D meson Analysis in Pb–Pb Collisions

A similar analysis strategy has been adopted for Pb–Pb data as for pp, but with a tighter selection due to higher combinatorial background. The $D^0 \rightarrow K^- \pi^+$ signal was measured in five p_t bins in the range $2 < p_t < 12$ GeV/c and the $D^+ \rightarrow K^- \pi^+ \pi^+$ signal in three bins in the

range $5 < p_t < 12$ GeV/c. The invariant mass spectra obtained for D^0 and D^+ for the 20% most central events are shown in Fig. 3.

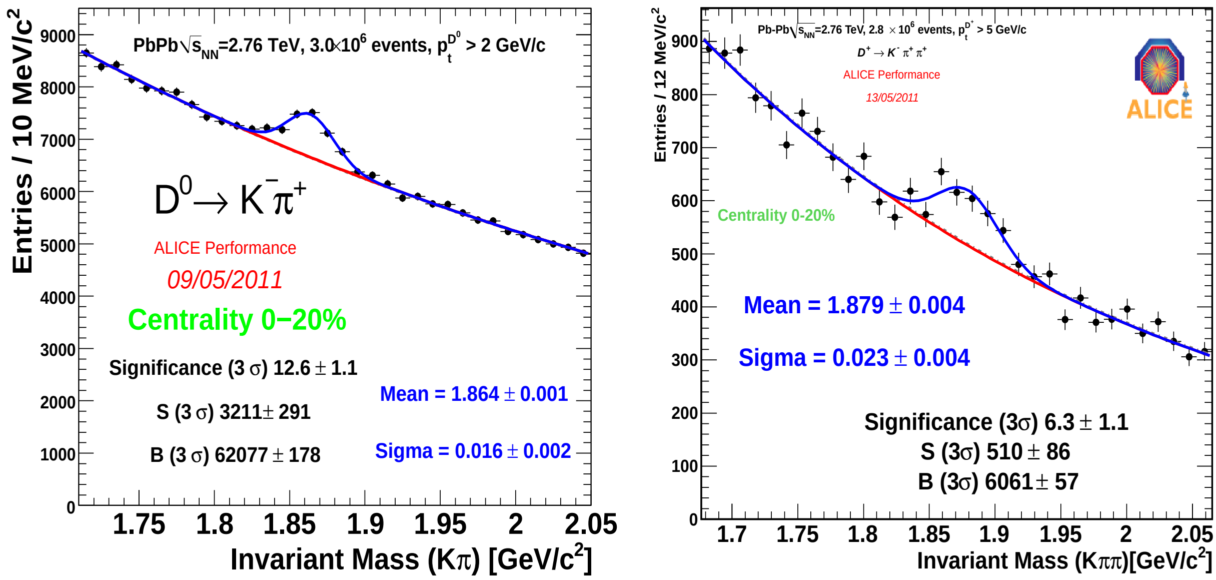

Figure 3. Left: Invariant mass distribution from 3 million central Pb–Pb collisions for D^0 candidates with $p_t > 2$ GeV/c, Right: D^+ candidates with $p_t > 5$ GeV/c

The raw signal is corrected for detector acceptance and efficiency using Monte Carlo simulations. The contribution of D mesons from B decays was evaluated using the FONLL prediction. This contribution is approximately 10-15 %. The effect of the unknown nuclear modification of beauty production was included in the systematics.

4.1. D meson Nuclear Modification Factor (R_{AA})

The nuclear modification factor (R_{AA}) of particle production is defined as:

$$R_{AA}(p_t) = \frac{1}{<N_{coll}>} \cdot \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t} = \frac{1}{<T_{AA}>} \cdot \frac{dN_{AA}/dp_t}{d\sigma_{pp}/dp_t}$$

where dN_{AA}/dp_t is the yield of D-mesons in Pb–Pb and $d\sigma_{pp}/dp_t$ is the cross section measured in pp. $< T_{AA} >$ is the average nuclear overlap function calculated with the Glauber model in the centrality range considered.

The cross-section was measured at $\sqrt{s} = 7$ TeV in the same momentum range, and must be rescaled to 2.76 TeV to allow a comparison with the Pb–Pb results at the same energy. This rescaling was done using FONLL calculation of the D-meson p_t-differential cross sections at the two energies [15]. We assume that the pQCD scale values (factorization and renormalization scales) and the c and b quark masses used in the calculation do not vary with $\sqrt{s}$. The theoretical uncertainty in the scaling factor was evaluated by considering the envelope of the scaling factors resulting from different values of the scales and heavy quark masses. The uncertainty in the scaling decreases from 25 % at $p_t = 2$ GeV/c to 10 % above 10 GeV/c. The scaling procedure was cross-checked by scaling the data to $\sqrt{s} = 1.96$ TeV and comparing with CDF results [3]. The procedure was also validated using the pp run at 2.76 TeV in the p_t range where the datasets overlap.

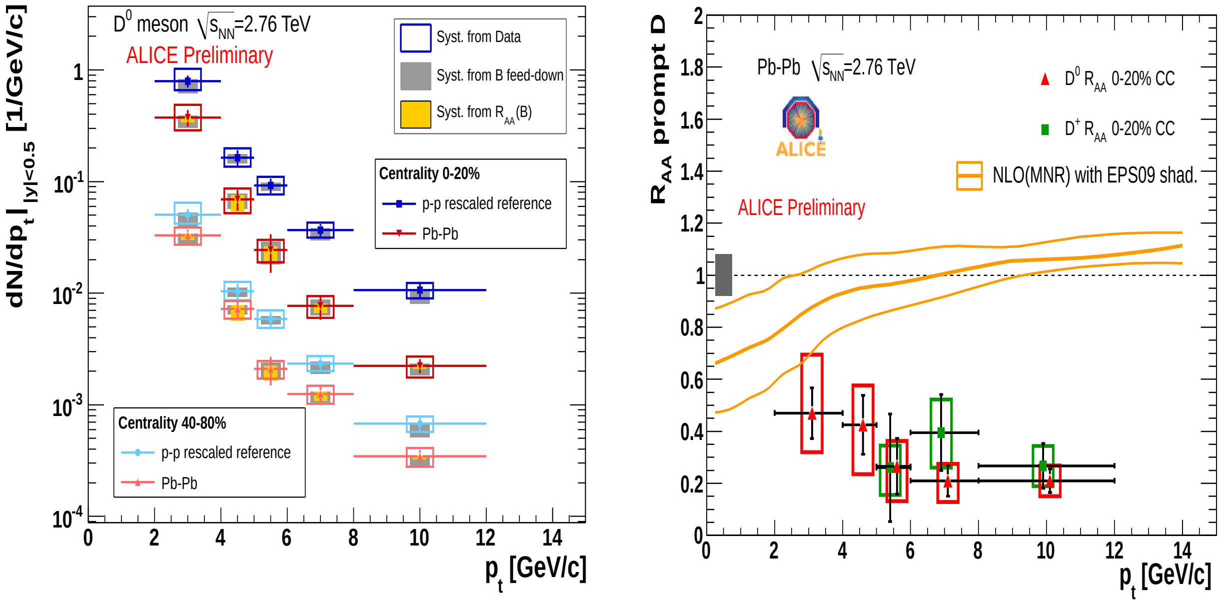

Figure 4. Left: D^0 yield in Pb–Pb central (0-20%) and peripheral (40-80%) collisions compared to pp reference spectra. Right: D^0 and D^+ R_{AA} compared with R_{AA} of D-meson from pQCD calculation based on MNR code and nuclear PDF from EPS09 parametrization

Fig. 4 (left) shows the D^0 p_t spectra measured in central (0-20%) and peripheral (40-80%) Pb–Pb collisions, compared to their respective reference spectra.

The D^0 production is suppressed by a factor 4-5 in central events for $p_t > 5$ GeV/c, as quantified by the nuclear modification factors shown in Fig. 4 (right). The D^0 and D^+ R_{AA} agree within errors. Several sources of systematic uncertainties were considered. They include uncertainties on the normalization to the total number of events, on the tracking efficiency, on the selection and PID efficiencies, on the signal extraction and on the p_t distribution of D-mesons used to estimate the efficiencies in Monte Carlo simulations. A systematic uncertainty related to the secondary D-meson R_{AA} was also taken into account by varying the value of R_{AA} of D mesons from B decays between 0.3 and 3 times the R_{AA} of prompt D mesons.

Nuclear shadowing yields a relatively small effect for p_t >5 GeV/c, as shown in Fig. 4 (Right) by the R_{AA} of D-meson expected from pQCD calculation based on the MNR code [16] and nuclear PDF from EPS09 parametrization [17]. Therefore, the observed suppression is an evidence of in-medium charm quark energy loss.

The D-meson nuclear modification factor was also compared to that of the charged pions [18], shown in Figure 5 (Left) and the two were found to be compatible for $p_t > 5$ GeV/c. Below 5 GeV/c, R_{AA} of pions seems to be smaller than R_{AA} of D-mesons, but improved statistics are needed to draw firm conclusions.

The centrality dependence of the D^0 R_{AA} is shown in Fig. 5 (right) for $6 < p_t < 12$ GeV/c. R_{AA} decreases from ~ 0.7 in peripheral (60-80%) to ~ 0.2 in central (0-10%) events.

5. Conclusions

The present status of the open charm analysis in ALICE has been shown. For pp collisions, we have shown preliminary measurements of the p_t differential production cross section of the D^0, D^+ and D^{*+} mesons at central rapidity. The measurements are well-described by the theoretical calculations within their uncertainties. In Pb–Pb central collisions, the nuclear modification

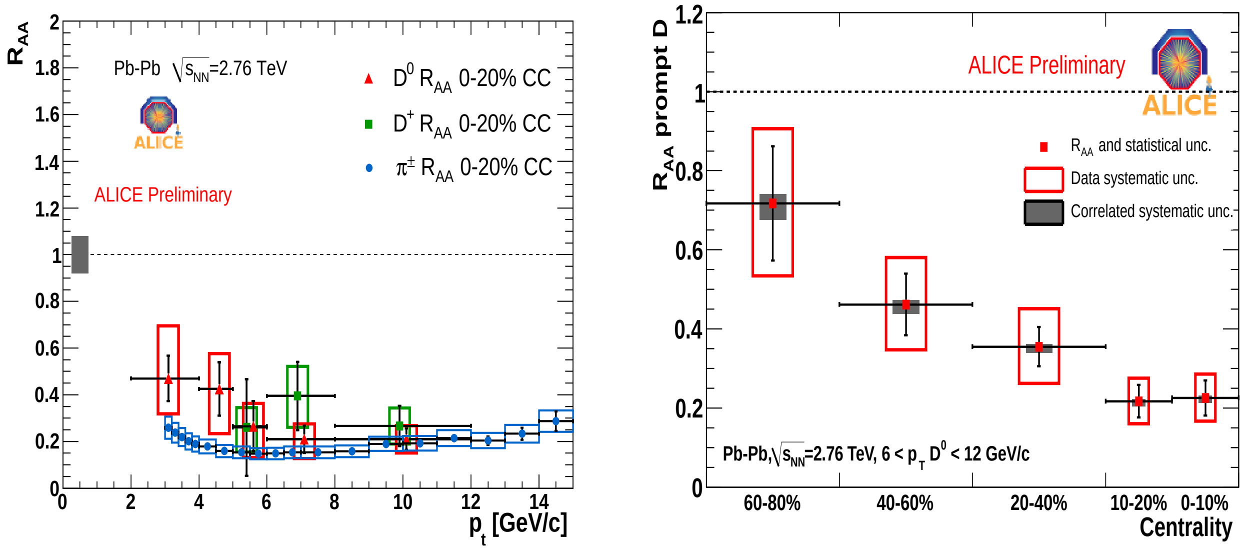

Figure 5. Left: Nuclear Modification factor for D^0 and D^+ compared to that of charged pions measured in central (0-20%) Pb–Pb collisions. Right: D^0 R_{AA} as a function of centrality for $6 < p_t^{D^0} < 12$ GeV/c

factors of D^0 and D^+ show a significant supression at $p_t > 5$ GeV/c and are compatible with the R_{AA} of pions. Below 5 GeV/c, there is a hint of possible hierarchy in the values of R_{AA} i.e, $R^D_{AA} > R^\pi_{AA}$. The higher statistics, expected from the 2011 Pb–Pb run should allow this to be confirmed and quantify the difference. In addition, the comparison data from p-Pb collisions should allow this region to be studied with greater precision and should disentangle initial-state nuclear effects, which could be different for light and heavy flavours.

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